Plate 3: Bedrock Geology and Topography—Expanded Explanation
City of Alexandria and Vicinity
By Tony Fleming, March, 2008

Introduction
Metamorphic bedrock of early Paleozoic age is present below the entire city, but crops out only in Holmes Run Valley and adjacent ravines in the far western section, where it is exposed by erosion along the modern fall zone. Elsewhere, the bedrock is buried beneath the eastward-thickening wedge of coastal plain sediments, and ranges from a few feet to several hundred feet below the modern land surface. Plate 3 depicts two main features of the bedrock: the elevation and topography of the buried bedrock surface, and the geology and structure of the various rock units at the bedrock surface.

Significance of the Bedrock Surface
The horizon represented by the bedrock surface marks a profound hiatus in the geologic record, referred to as an *angular unconformity*, during which some 300+ million years of geologic time is unaccounted for between the deposition of the early Cretaceous Potomac Formation and the early Ordovician Taconic Orogeny, when most of the local bedrock originated. "Angular" unconformity refers to the fact that the bedrock was folded, metamorphosed, and eroded to a surface of low relief before the deposition of the overlying Potomac Formation which, other than being gently tilted to the southeast and locally affected by faulting, is essentially undeformed. Because there are no intervening geologic units, the bedrock surface also represents the altitude of the base of the Potomac Formation, and its topography preserves the basic configuration of the lower Cretaceous depositional basin in which the Potomac sediments accumulated. A basic understanding of the topography of the bedrock surface is therefore crucial to several aspects of mapping the subsurface geology of Alexandria, particularly the details of the overlying Potomac Formation. Buried bedrock valleys, for example, suggest riverine channels where major bodies of sand (channel and point bar facies) were deposited and may have substantial lateral and vertical extent. On the other hand, the summits of bedrock hills and ridges and the lees behind them may be places where muddy sediments accumulated, while some of the broader "flats" on the bedrock surface suggest swampy floodplains and meandering river valleys where a more varied sediment assemblage was deposited. Knowledge of the bedrock surface configuration allows reliable estimates to be made of the total thickness of the Potomac Group, which in turn enables downdip reconstruction of the different sedimentary facies that comprise its various intervals. From a modern environmental standpoint, in the western part of the map area where the bedrock surface is close to modern base level, it forms an important confining unit whose elevation determines the locations of springs, seeps, and other ground-water discharge from the sandy basal Potomac aquifer, which constitutes the source of base flow for numerous streams and wetlands. Finally, the historical geology of the early Paleozoic bedrock is a fascinating story in its own right, and the rocks exposed in the western part of the city reveal a wide variety of features of great educational, ecological, and scientific value.

Previous Studies
There have been no prior attempts to systematically map the bedrock surface at a detailed scale in Alexandria specifically, though the city was vicariously included in a broader mapping effort by the US Geological Survey in the 1970's and 1980's focusing on Fairfax County. As a part of that effort, Drake and Froelich (1986) mapped the geology of the Annandale Quadrangle, which encompasses the far western sections of the city, while Daniels (1980) interpreted the bedrock geology beneath the coastal plain of Fairfax County using geophysical data. Froelich (1985) included a small-scale map showing the inferred extent and altitude of the base of the Potomac Formation; the map shows relatively few data points in the city, relative to adjacent areas in Fairfax County. Huffman (1975) included the city in a bedrock geology map of northern Virginia inside the Capital Beltway. Prior to that, Darton (1950) described several wells and made a number of observations concerning the bedrock surface in the vicinity of Seminary Ridge, while Johnston (1964) field located, mapped, and obtained descriptions of known water wells throughout the region. Plate 3 combines new information collected during the present study with the observations and interpretations from these earlier efforts into a unified interpretation of the bedrock beneath the whole city.

Data Sources, Uses, and Methods
All of the aforementioned reports served as sources of data for the present study; these were supplemented by the collection of extensive sets of geotechnical borings obtained from the city and VDOT, and by numerous observations of the bedrock and lower Potomac Formation in natural outcrops and excavations throughout the western part of the city. The locations of all of the various data used for all aspects of this study are given on Plate 1: Map Showing the Distribution and Sources of Data, and the details are described in the "Plate 1-Expanded Explanation" and in three associated databases. The following section provides a brief review of the types and sources of data used specifically to construct plate 3; the locations of specific outcrop, well, and borehole data used to determine the elevation of the bedrock surface are also shown on plate 3.

Outcrops were primarily useful in the far western part of the city, where bedrock is exposed or close to the modern land surface. In addition to numerous outcrops showing the lithology and structure of the bedrock itself, the base of the Potomac Formation and its contact with the underlying bedrock was directly observed or could be reliably inferred at many locations along the valley walls of Holmes and Four Mile Runs and their major tributaries. The contact is widely exposed in ravines in Dora Kelley and Rynex Natural Areas in western Alexandria, as well as in Barcroft and Glencarlyn Parks in southern Arlington County, where it is typically marked by a line of seeps and springs caused by abundant discharge of ground water from the sandy units that comprise the base of the Potomac Formation. Work done previously by the author at Green Spring Garden Park in nearby Turkeycock Valley also provided insights concerning local bedrock topography and the location of a significant buried bedrock valley in that area.

The records of a large number of wells and boreholes figured prominently in the interpretation of the elevation and configuration of the bedrock surface, especially in the coastal plain section of the city where bedrock is not exposed. The single largest set of subsurface data in the city is from Johnston (1961, 1964), who documented the locations and characteristics of some 150 historical wells in and adjacent to the city, many of them fairly deep. Although only 6 of the wells have formation logs describing the geologic materials encountered during well construction, all of them are summarized by total depth, casing length, aquifer they are developed in, and other features that can be useful, though not necessarily definitive, for inferring the elevation of the bedrock surface. For example, large wells are commonly developed in the thick sands at the base of the Potomac Formation, and it was a common practice to "seat" the well casing on or just into the bedrock surface; thus the casing lengths given by Johnston can often act as a proxy for depth to bedrock. Darton (1950) documented the locations and depths of 30 wells in and near the map area, some of which penetrated to bedrock and thus provide an absolute elevation of the bedrock surface. Other wells did not reach bedrock, but are nevertheless important because they indicate the minimum depth (maximum elevation) of the bedrock surface. Froelich's (1985) maps also show about 30 unique boreholes in and near the city that give the altitude of the base of the Potomac Formation. Geotechnical borings were obtained from the city and VDOT for more than 100 building sites, highway interchanges, schools, and other infrastructure projects. The bedrock surface was encountered at only five of the boring sites, but relatively deep borings that did not reach bedrock at many other places were just as useful for constraining the maximum elevation of the bedrock surface at these sites.

Information on the geology and altitude of the bedrock surface from all of these sources of data was plotted on a 1:24,000 base map encompassing all of the Alexandria and the eastern half of the Annandale 7.5-minute topographic quadrangles. A larger area was selected for this exercise in order to provide the broader, regional context that defines the bedrock surface within the city. In this way, the bedrock structure contours that appear on plate 3 were generated, using a nominal 100-foot contour interval to show the configuration of the bedrock surface beneath the city. The density and quality of data are significantly better in the western part of the map area where the bedrock surface is exposed or proximal to the surface, so supplemental 50-foot structural contours were utilized to depict additional topographic details for the part of the bedrock surface above sea level.

Bedrock Geology Beneath the Coastal Plain

Aeromagnetic maps of the Alexandria and Annandale 7.5-minute quadrangles allow the bedrock geology to be interpreted beneath the Coastal Plain with reasonable confidence, despite a lack of exposure. The aeromagnetic signature is almost entirely the result of the magnetic properties of the bedrock, and is little affected by the overlying Coastal Plain deposits. Consequently, by comparing the aeromagnetic anomalies of known rock units and structures exposed in adjacent parts of the Piedmont, and tracing these beneath the Coastal Plain cover, it is feasible to make some first-order approximations of gross bedrock lithology and structure. These lithological interpretations are aided by descriptions of the bedrock encountered in scattered deep wells. Daniels (1980) made such an interpretation for all of Fairfax County, using both aeromagnetic and gravity data. Much of the geologic interpretation presented herein is based on Daniels' report, but is modified by my own knowledge and experience with these rocks, especially in the adjacent Washington West Quadrangle just to the north and in adjacent parts of Holmes Run gorge and other nearby stream valleys where bedrock is well exposed.

Bedrock Topography and Configuration of the Base of the Potomac Formation
The overall map pattern indicates a relatively smooth bedrock surface that slopes east-southeast at an average rate of about 100-110 feet per mile across the city, with some local variation in the structural gradient. The bulk of the apparent dip is attributable to west-to-east tectonic tilting of the entire regional landscape following, and possibly during, deposition of the Potomac Formation. The relatively smooth appearance of the bedrock topography may be an artifact of the overall thin data density: where bedrock data are more abundant in the western part of the map area (generally corresponding to bedrock surface altitudes at or above sea level), the bedrock surface beneath the Potomac Formation shows noticeably greater local relief, including several narrow, but relatively well defined valleys. Whereas to the east, data points that reach the bedrock surface are fewer and more widely scattered, resulting in a flatter-looking, more interpolated bedrock surface altitude. It is noteworthy in this context that the bedrock surface shows considerable local relief at places where subsurface data are concentrated, notably on the part of Seminary terrace in Alexandria where Darton (1950) presents closely-spaced well data, and in the Green Spring Garden Park segment of Turkeycock Valley, where a prominent, sand-filled bedrock valley is well defined by outcrop, water well, and hydrogeological data (Fleming, 2005). Considerable local relief along the contact is also suggested by variations in the elevation of the contact observed in outcrops in Holmes Run Gorge. Given sufficient data, it seems likely that much more local relief would be apparent on the bedrock surface than can be shown with the present data set.

The data suggest the presence of several valleys incised into the bedrock surface to various degrees. The largest of these extends westward beneath the south side of Cameron Valley; two or more tributaries appear to converge into the main bedrock valley in the vicinity of South Van Dorn Street. Fingers of this valley system, referred to herein as the “Cameron bedrock valley”, appear to extend all the way to the Coastal Plain boundary to the west. A second, somewhat less well-defined valley more or less parallels Four Mile Run before bending west toward the Baileys Crossroads area. Segments of smaller(?) valleys can be identified locally, but their true extent, continuity, and relation to the larger bedrock valleys is not always readily defined using existing data. The Turkeycock Run/Green Spring Garden bedrock valley, for example, which is responsible for the outlier of Potomac Formation that extends west through Pinecrest, appears to continue southeastward below Lincolnia toward Holmes Run, but is increasingly ill defined in that direction. It may cut through the valley walls in the heavily urbanized section of Holmes Run between Shirley Highway and Beauregard Street, or it may continue southeast in the direction of Backlick Run, as it is currently depicted on plate 3. Which of these alternatives is correct is ultimately a matter of speculation given the absence of definitive data in either area.

As the Potomac Formation began being deposited in the early Cretaceous, such bedrock valleys would have served as likely locations of relatively high-energy river channels, hence coarse-grained channel fills of considerable longitudinal extent might reasonably be expected to be found along and near the thalwegs of the valleys. Some of these large channels may have persisted through time in the same locations as the Potomac depositional basin evolved: major trunk streams that occupied the valleys could have easily produced and perpetuated broad, alluvial lowlands in the early Cretaceous landscape, in which stream flow remained concentrated. This relationship is clearly the case for the Cameron bedrock valley, where a stack of major sand bodies extending well into the upper intervals of the Potomac Formation is documented by Froelich (1985), and to a similar, but less well-defined extent along the Four Mile Run bedrock valley, where large sand bodies up to 100 feet thick crop out above the bedrock surface along the modern valley walls. The extensive bodies of sand that crop out along lower Holmes Run may also be localized within a bedrock valley. However, this relationship is by no means universal, and it seems likely that bedrock valleys became less significant in determining the distribution of river channels and other sedimentary facies higher in the Potomac Formation, as the bedrock surface became increasingly deeply buried by Potomac sediments and thus isolated from the early Cretaceous landscape.

Bedrock Geology of Holmes Run Gorge

Exposed bedrock in western Alexandria and adjacent areas consists of metamorphosed sedimentary rocks intruded by early Ordovician plutons of tonalite and granite. In the early Paleozoic, the rocks that now underlie Alexandria were not part of North America. Most, and perhaps all of them, formed in and below a subduction zone known as the Taconic Arc, which lay somewhere off the coast of early North America. At that time, the crust of an ancient ocean was being subducted eastward beneath an island arc, producing a large range of volcanoes. The bedrock terrane we now think of as "Alexandria" (indeed, most of the greater DC area) arrived when the Taconic Arc eventually collided with and was accreted to North America later in the Paleozoic, when the direction of subduction flipped from east to west.

The principal metasedimentary rock unit exposed in the city is the Indian Run Formation Drake, 1985), a metamorphosed sedimentary mélange, or diamictite, which very likely accumulated near the bottom of a submarine trench at the base of the Taconic subduction zone. This rock unit is characterized by scattered quartz pebbles, small "wafers" of mica schist, and larger slabs and fragments of metamorphosed sandstone, schist, volcanic rocks, and other exotic rocks floating in a massive, quartzofeldspathic matrix. The rock lacks stratification in any usual sense of the word, and appears to have formed in part by submarine sliding of unconsolidated sediments along the sides of the submarine trench. The slumping and sliding may have been triggered by a combination of nearby volcanic activity and the arrival of thrust sheets bearing the exotic rocks that are now seen as fragments, or "olistoliths", within the mélange. A considerable portion of the sediment that makes up the Indian Run is non-marine in origin: well rounded quartz pebbles and sand-sized grains of quartz and feldspar are clearly of continental origin and may have been delivered to the trench via large river systems draining a nearby landmass, by tidewater glaciers (some of the clasts show decidedly "flatiron" shapes characteristic of a glacial origin), or some combination. On the other hand, a considerable part of the matrix consisted of mud (now metamorphosed to mica and fine feldspar) that probably did accumulate in a deep marine environment, presumably along the sides of the submarine trench. Repeated slumping and sliding mixed the sediment from different sources, a process that continued for a period sufficiently long to accumulate thousands of feet of mélange with a relatively homogeneous matrix. Although its top and bottom are not exposed, the Indian Run may be more than 10,000 feet thick. Most of the rock exposed within the city is generally clast poor, containing only scattered quartz pebbles and small schist chips. Good examples of mélange containing abundant large fragments of exotic rock can be seen in southern Arlington County along Four Mile Run in Glencarlyn Park, where it contains giant slabs of sandstone and schist up to 20 feet in length that stand at all angles to one another. The rock exposed in the bed of Holmes Run downstream from Shirley Highway also contains abundant inclusions. The Indian Run Formation is very similar to the Laurel Formation in Rock Creek Park (DC) and adjacent parts of Maryland (Fleming and others, 1994; Fleming and Drake, 1998), and there is a strong chance that the two are the same unit, offset by about 10-15 miles along the Rock Creek Shear Zone (see the following section on ***Bedrock Geology of the Coastal Plain***).

Two other metasedimentary rocks—the <u>Lake Barcroft Metasandstone</u> and the <u>Accotink Schist</u>—crop out in very limited areas within the city. These two rock units collectively form the Annandale Group (Drake and Lyttle, 1981), which crops out extensively just north and west of the city, and which appears to constitute the source of sandstone and schist fragments observed in the Indian Run mélange. The Accotink Schist consists of coarse-grained, well-bedded mica-quartz schist that crops out in one or more strongly folded bodies in the streambed in Rynex Natural Area. There, it is intruded by many small bodies of Occoquon Granite, making it difficult to determine its relation to the nearby Indian Run Formation: the body may represent one or more large olistoliths within the mélange, or it may be a complex infold of the main Annandale body, which lies just northwest of the map area and overlies the Indian Run on the Red Fox thrust fault. One body exposed along the west bank of Holmes Run near the mouth of the Rynex ravine forms a narrow screen between bodies of Falls Church Tonalite and Occoquon Granite, and appears to contain kyanite and/or sillimanite that have largely been retrograded to shimmer aggregates of fine white mica. The only body of Lake Barcroft Metasandstone even marginally large enough to show on the map is immediately upstream of Shirley Highway, and appears to be a swarm of small to large xenoliths of light colored, fine- to medium-grained quartzitic sandstone engulfed by Occoquon Granite. A few thin beds of similar sandstone occur within Accotink Schist in Rynex Natural Area.

The principal intrusive rock exposed in the city is the <u>Occoquon Granite</u>, which forms the nearly continuous series of scenic, water-sculpted ledges upstream of Beauregard Street, and numerous other outcrops elsewhere in Holmes Run Valley. Most of the rock consists of well-foliated, light gray, biotite-muscovite granite and granodiorite. Many outcrops exhibit two foliations and evidence of multiple generations of folds. Contacts with the adjacent metasedimentary rocks range from sharp to muddled, and are commonly folded. Inclusions are relatively sparse and tend to be concentrated near the main contact with the Indian Run Formation. Small dikes and patches of granite are locally abundant in the metasedimentary rocks near contacts. In the larger picture, the Occoquon Granite occupies a sizable part of southeastern Fairfax County—an area sufficiently large to constitute a small batholith (Drake and others, 1979). The strongly folded northern margin of the batholith runs right through the western part of Alexandria and is responsible for the complex outcrop pattern of granite and metasedimentary rocks in Holmes Run Valley and Rynex. Falls Church Tonalite (Drake and Froelich, 1986) crops out in one small body along the west bank of Holmes Run, immediately below the outfall of the Rynex ravine. It consists of medium gray, medium- to coarse-grained hornblende tonalite that locally contains a sizable number of black inclusions of mafic rock. The tonalite is strongly foliated in this exposure and appears to be intruded by at least one dike of Occoquon Granite. A considerably larger body of the tonalite crops out about a mile upstream of the city limits, just below Columbia Pike; and a very large body underlies most of the City of Falls Church. Very light colored muscovite monzogranite (Drake and Froelich, 1986) crops out along Holmes Run starting less than 150 feet west of the city limits, and extends upstream along the west bank for almost 3,000 feet. The rock is pinkish-white in color and ranges from sugary textured to coarse grained. Small dikes of similar rock can be seen at several places in the city, such as Rynex ravine.

Reliable age determinations were recently made (Aleinikoff and others, 2002) on individual zircon crystals from the Occoquon Granite (472 $\pm$ 4 ma) and Falls Church Tonalite (469$\pm$6 ma). These ages are broadly comparable to those for the majority of intrusive rocks in the region, and support the concept of a widespread magmatic arc in early to middle Ordovician time, i.e., the Taconic Arc. The metasedimentary rocks are clearly older since they are intruded by Occoquon Granite and Falls Church Tonalite. The Indian Run presumably accumulated in the same subduction zone that generated the magmatic arc, hence parts of this unit could be as young as early Ordovician, though most of it probably dates from the Cambrian, when the submarine trench and subduction zone are presumed to have originated. Insofar as the Indian Run contains fragments of the Annandale Group, the latter rocks are tentatively considered to be Cambrian or late Proterozoic in age. The age of the muscovite monzogranite is unknown, but it is probably similar to the other intrusive rocks. Drake and Froelich (1986) presented evidence that it is intruded by Falls Church Tonalite, and is thus somewhat older.

At least two fold phases are evident in the rocks exposed in Holmes Run Gorge, and they control the map pattern in that area. The earlier phase consists of open, north-to northeast-trending folds that control the broad outlines of the granite contact. An excellent example can be seen in a set of large outcrops along the west side of Holmes Run at station 146 in Dora Kelley Park (see Plate 1), where an antiformal mass of granite plunges gently northeast, with the metasedimentary wallrocks of the Indian Run arched up over it. At many places, the rocks are refolded about a younger set of tight, isoclinal folds that trend north-northwest. A strong, steeply west-dipping cleavage with retrograde mineral assemblages is locally developed parallel to the axial surfaces of the later folds. Drake and Froelich (1986) identified several fold generations in the Annandale Quadrangle; the older and younger folds observed in Holmes Run most likely correspond to their Clifton and Accotink folds, respectively. Since both fold phases deform the contacts of the granite, both are synchronous with or younger than the emplacement of the 472 ma Occoquon Batholith.

Bedrock Geology of the Coastal Plain

A large part of the Coastal Plain section of the city appears to be underlain at depth by the Indian Run Formation and Occoquon Granite: the aeromagnetic signatures of these units can be traced from their outcrop in Holmes and Turkeycock Runs to beneath the western and central parts of the city. The contact between them forms a gentle but continuous aeromagnetic gradient that runs south from Holmes Run, more or less paralleling South Van Dorn Street across Cameron Valley into southeastern Fairfax County. The gradient separates the distinctive pattern of closed magnetic highs and lows associated with the Indian Run Formation from the monotonous, nearly flat magnetic anomaly of the Occoquon Batholith. A prominent, deep, somewhat heart-shaped aeromagnetic low centered on Fort Ward underlies the northern part of the city, and appears to mark a previously unrecognized body of intrusive rock. "Granite" was reported by Darton (1950) from at least two old wells in the vicinity of the Episcopal Seminary that coincide with the aeromagnetic low. The composition of this body is unknown and is shown as undifferentiated granitoid rocks on plate 3. It could be a satellite body of Occoquon Granite, but the deep aeromagnetic low much more closely resembles the pattern associated with plutons of Falls Church Tonalite.

The bedrock geology beneath the eastern part of the city, and especially Old Town, appears to be considerably different and more complex. The principal bedrock unit exposed immediately north of the map area in the southern part of the Washington West Quadrangle (Fleming and others, 1994) is the Sykesville Formation, which presumably extends southward beneath Alexandria. This rock unit is a sedimentary mélange that is generally similar in character and origin to the Indian Run, but differs slightly in the type of inclusions it contains. The exact relationship between the Sykesville and the Indian Run Formations is speculative. In the Annandale and Falls Church Quadrangles (Drake and Froelich, 1986; 1997), the Sykesville is interpreted to overlie the Indian Run and Annandale Group on the Burke Thrust Fault; the Sykesville, and the thrust fault, are presumed to extend southward into Alexandria. As shown on plate 3, the thrust fault is inferred to follow a moderate to weak, arcuate aeromagnetic gradient that separates the distinctive pattern of closed magnetic highs and lows associated with the Indian Run from the broader magnetic low of the Sykesville. On the other hand, there is no clear field evidence in southern Arlington County that a major fault separates the two formations, and it is within the realm of possibility that they could simply be different parts of the same mélange, perhaps deposited in longitudinally different parts of the same submarine trench, or in the same part of the trench at different times. Resolution of this question is well beyond the scope of the present project.

The dominant aeromagnetic feature in the eastern section of the city is an intense, quarter- to half-mile-wide, south-to southwest-trending lineament that enters the northeastern corner of the map area near National Airport, follows the toe of the Mt Ida escarpment below Del Ray, before crossing Cameron Valley and continuing in the same direction into southeastern Fairfax County beneath the prominent topographic sag occupied by Telegraph Road. This pronounced geophysical anomaly is the southward continuation beneath the coastal plain of the Rock Creek Shear Zone (RCSZ, Fleming and Drake, 1998), a major fault zone well exposed for many miles in the Washington

West and Kensington Quadrangles to the north. Rocks within the RCSZ are sheared into fine-grained ductile mylonites that are virtually unrecognizable from their original state. The intense deformation reflects a long, complex history of both strike-slip and reverse fault motion, which began in the Ordovician with major sinistral (left lateral) strike-slip displacement, was reactivated in the later Paleozoic by strong dextral (right lateral) slip, and was then followed by west-side-up reverse faulting that more or less continued into the Pleistocene. Based on visible offset of young river terraces near the National Zoo in Rock Creek Park, the fault zone is inferred to remain potentially active, though no modern seismicity has been recorded. It may or may not be significant that the trace of this fault zone so closely follows the Mt Ida escarpment, which separates the central and western highlands of the city from the massive late Pleistocene river terrace occupied by Del Ray and Old Town; available data are not sufficiently robust to determine whether there is any structural control on the position of the escarpment, but the geographic coincidence is certainly intriguing.

The RCSZ forms a major tectonic boundary in DC, and the same is inferred to be the case here. The aeromagnetic pattern west of the lineament is consistent with the Indian Run Formation (± the Sykesville Formation) intruded by the Occoquon Granite. The aeromagnetic pattern east of the shear zone is distinctly different, however, and extends southward for some 10-20 miles into the type area of the Chopawamsic Formation, which consists of metamorphosed, fine-grained mafic to felsic volcanic rocks. Daniels (1980) interpreted the pattern east of the lineament to represent the Chopawamsic, and reports of "green rock" and "flint" from wells that penetrated bedrock beneath Old Town and Huntington bolster this conclusion. Based on the available data, it appears that the bedrock surface below virtually all of Old Town is composed of metavolcanic rocks of this formation. Like the intrusive rocks in this area, the Chopawamsic is also early to middle Ordovician in age, and may well represent material erupted from the Taconic Arc. A sharp aeromagnetic and gravity anomaly located beneath the river just south of Old Town probably represents a body of granitoid rock, perhaps another pluton of Occoquon Granite, with which the Chopawamsic is intimately associated in its type area. There is a strong likelihood that the Occoquon (and possibly other intrusive rocks, such as the Falls Church Tonalite) represent the intrusive equivalents of the Chopawamsic, in essence the deep, magmatic roots of the Taconic Arc.

Cretaceous-Cenozoic Faulting and Tectonics

The eastward slope of the bedrock surface is a manifestation of the overall west-to-east tilting of the mid Atlantic Piedmont and fall zone that has occurred since the early Cretaceous. The role of faults and flexures in this process is recognized at several places (Prowell, 1983). Examples of young faulting that affects the bedrock-Coastal Plain contact are well documented in this part of the mid Atlantic, including the Brandywine fault zone of southern Maryland (Jacobeen, 1972), the Stafford Fault Zone, just southwest of Fairfax County (Mixon and Newell, 1976; 1977; 1978; Newell and others, 1976), the Mountain Run Fault Zone of central Virginia (Pavlides and others, 1983), and the even more proximal Rock Creek Shear Zone in Washington, D.C. (Fleming and others, 1992, 1994; Fleming and Drake, 1998). In all of these cases, the post-Cretaceous faults are known or thought to occur within older, Paleozoic fault zones that have been reactivated.

For a variety of reasons, post-Cretaceous faults may not be readily apparent, either in the field or the mapping process. For example, the soft, poorly consolidated coastal plain sediments where relatively young faults are most easily recognized tend to make fewer and smaller outcrops (relative to the hard bedrock). Likewise, it is difficult to recognize faults from subsurface data because reliable, continuous lithological markers are sparse, especially in the Potomac Formation, with its many abrupt facies changes. Therefore, it is highly unlikely that isolated Coastal Plain faults are going to be found, barring a fortuitous exposure. But the well-documented association between post-Cretaceous faults and older, Paleozoic fault zones can be used to advantage to identify potential zones of young faulting, since Paleozoic fault zones, especially the larger ones, typically produce a readily recognizable aeromagnetic signature. For this project, the aeromagnetic anomalies in the Alexandria area were closely scrutinized to identify potential fault zones concealed beneath the Coastal Plain. This process identified at least two major zones of deformation cutting across the bedrock surface in the map area. One of these is clearly the southward continuation of the Rock Creek Shear Zone, which was noted earlier. It is interesting to note that Daniels (1980) also interpreted this aeromagnetic feature as a fault zone, long before the RCSZ was ever recognized in the field. The RCSZ is a strong candidate for post-Cretaceous faulting, as it contains many young faults in Rock Creek Park. A second lineament, marked by a moderately strong aeromagnetic gradient, parallels Holmes Run Gorge and continues south-southeastward across Cameron Valley, following a series of linear sags to its convergence with the RCSZ lineament near the northwest corner of Hybla Valley. The trace of this feature is indicated on plate 3 by the large dashes. The source of this anomaly is not clear because it largely lies outside of the area where bedrock crops out.

There is some suggestion that the bedrock surface is affected by post-Cretaceous faulting in the map area. The -200, -300, and -400-foot structure contours become somewhat more tightly bunched and show a noticeable dextral deflection across the aeromagnetic lineament marking the RCSZ. Likewise, the structure contours between sea level and +250 feet also show bunching and dextral deflection across the Holmes Run Gorge lineament. This area features the greatest bedrock surface gradients anywhere in the map area, apparently approaching 150 feet per mile in small areas. These features imply that the western part of the map area has been uplifted relative to the eastern part, possibly along a series of en-echelon high-angle reverse faults that broadly parallel the two aeromagnetic gradients noted earlier.

Although not directly exposed at the surface, two potentially substantial fault zones with west-side-up tectonics are inferred within the map area from apparent offset of early Cretaceous strata and much younger upland river terraces. The more conspicuous of the two, dubbed the "Fort Williams fault" runs northeast from Fort Williams Park to Chinquapin Park. A second fault is inferred to run north-south near the mouth of Taylor Run. These faults are highlighted on the map of the Potomac Formation (plate 4), where their effects are most apparent. This structural style would be similar to what has been documented in the nearby Stafford and Rock Creek fault zones, with displacement along any given fault being relatively small (mostly a few feet or less), but with a potentially much greater cumulative displacement (hundreds of feet of cumulative displacement are documented along the Stafford Fault Zone, and a similar amount is likely along the Rock Creek Shear Zone).

The precise age of the inferred faulting is unknown; it is possible that some motion may have occurred during deposition of the Potomac Formation in the early Cretaceous: assuming that cumulative displacement may have been on the order of 100+ feet, one is tempted to think that the thin outer edge of the Potomac Formation would have been completely removed by erosion had the faulting all post-dated its deposition. Instead, that hasn't happened, and the result suggests more of a general, step-like upwarp of the bedrock surface to the west. If the faulting occurred syn-depositionally, the river system that deposited the Potomac Group could have easily eroded off the small scarps and buried them with sediment. On the other hand, well-developed modern topographic lineaments associated with both of the major aeromagnetic gradients offer a tantalizing suggestion of more recent fault motion. The massive Mt. Ida escarpment, in particular, almost perfectly parallels the aeromagnetic gradient associated with the southward continuation of the Rock Creek shear zone. The relationship is strongly suggestive, though due to heavy urbanization, no evidence to directly support a tectonic influence on the scarp has been uncovered. Likewise, the central section of the modern Holmes Run Gorge is nearly perfectly straight, and parallels the nearby aeromagnetic lineament, as if following some kind of major fracture zone. Several, valley-parallel bedrock faults and shears were observed in Holmes Run Gorge during this study, along with one reverse fault that cuts the bedrock-Coastal Plain contact by several feet close to the trace of the aeromagnetic lineament (at site 153, in Dora Kelley Park), lending support to the idea that more recent reverse fault motion has occurred here.

Origin and Significance of the Fall Zone

The fall zone is the dominant geological feature in Alexandria City and adjacent parts of Arlington and Fairfax Counties, and is developed along the feather edge of Coastal Plain sediments as they overlap crystalline bedrock of the Piedmont. The Coastal Plain sediments in this area consist of lower Cretaceous fluvial, swamp, and freshwater estuarine deposits (Potomac Formation), which form a rapidly east-to-southeast-thickening wedge across Alexandria. These sediments were deposited on a gently eastward-sloping, weathered bedrock surface of low to moderate relief, characterized in places by broad valley thalwegs and elsewhere by more irregular knobs and hills.

The Potomac Formation is thought to have originally extended far west of its present outcrop, but gradual tilting of the landscape from west to east has caused the western parts of the unit to be eroded off, and has led to active and ongoing dissection of the bedrock surface outboard of the current Potomac Formation margin, and in the valleys of large trunk streams, such as Four Mile, Holmes, and Turkeycock Runs. The modern landscape largely developed during the Pleistocene, in response to repeated episodes of continental glaciation that lowered global sea level and caused greatly accelerated downcutting and headward erosion by all of the area streams. A large part of the stream dissection manifested currently by the "fall zone" represents continuing upstream propagation of a pulse of late Wisconsin eustatic sea level decline and associated stream adjustment to the new base level. Holmes Run Gorge is an excellent example of this process in Alexandria. In any event, the configuration of the bedrock surface in areas of active incision, where the Coastal Plain sediments have been stripped off, generally bears little resemblance to the early Cretaceous depositional surface upon which the Potomac Formation was laid down.

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